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for

COMPENSATION FOR DC BALANCING OF LIQUID CRYSTAL DISPLAYS

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COMPENSATION FOR DC BALANCING OF LIQUID CRYSTAL DISPLAYS

SUB A17 This application claims the benefit of U.S. Provisional Application No. 60/034,447 filed December 27, 1996.

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The invention relates to DC balancing of ferroelectric and/or bipolar liquid crystal displays, particularly when used in reflective mode.

2. DESCRIPTION OF THE RELATED ART

DC balance is required of all liquid crystal displays. For twisted nematic (TN) materials, this is simply done by driving the individual cell with an AC waveform. This approach works well for TN materials because the molecules do not change physical state appreciably when the AC waveform changes electrical polarity. However, it does not work well with binary materials, such as ferroelectric liquid crystal (FLC) materials. When the polarity changes in FLC materials, the individual cell molecules change state, for instance, from on to off, turning off the cell. Thus, the individual cell must be turned off for approximately one-half of the time. This greatly reduces overall efficiency and brightness of any display built using FLCs.

One approach to solving this problem for transmissive mode FLCs is to include an additional ½-wave plate compensating FLC in the system. The primary

imaging FLC is a ½-wave plate and is placed in series with the additional ½-wave plate, which is a single cell. The compensating FLC is switched in synchronism with the imaging FLC so that the light polarization orientation is rotated 90 degrees by the compensating FLC prior to reaching the imaging FLC. As a result, the light is in the opposite state from normal, and the polarity reversed imaging FLC will now behave as normal. When the imaging FLC is not polarity reversed, the compensating FLC is turned off, the polarization of the light is not changed, and the imaging FLC operates normally. The compensating and imaging FLCs thus both maintain DC balance, and yet the reversed state of the imaging FLC does not produce a superimposed negative period.

While this solves the problem for transmissive mode FLC operation, it does not solve the problem for reflective mode FLC operation. In reflective mode operation, the FLC is a ¼-wave plate and light passes through the FLC to a mirror and returns back through the FLC, resulting in a total ½-wave retardation. However, if a ½-wave plate compensating FLC is used, the result of the compensating FLC is zero or full-wave retardation. Full-wave retardation produces the same result as if there were no compensating FLC at all, so that any light is still a negative. So a solution is needed to recover the efficiency in the reflective mode use of an FLC.

SUMMARY OF THE INVENTION

In one aspect of the present invention, an apparatus is provided which includes a wave plate having wave plate states, wherein the wave plate propagates light with a resulting polarization dependent on which of the wave plate states the wave plate is in. The apparatus further includes an imager having imager states, wherein the imager propagates the light from and to the wave plate with a resulting other polarization dependent on which of the imager states the imager is in, the imager imparting information on the light.

In another aspect of the present invention, a method of compensating in an optical system is provided. The method includes: (1) providing polarized light; (2) retarding the polarized light; (3) imparting information on the retarded polarized light; (4) reflecting the retarded polarized light; and (5) further retarding the reflected and retarded polarized light.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and advantages of the invention will become apparent upon reading the following detailed description and upon reference to the drawings in which:

Figs. 1A and 1B are illustrations of prior art uncompensated, transmissive mode FLC operation;

Figs. 2A and 2B are illustrations of prior art uncompensated, reflective mode FLC operation;

Figs. 3A, 3B, 3C and 3D are illustrations of prior art compensated, transmissive mode FLC operation; and

Figs. 4A, 4B, 4C and 4D are illustrations of properly compensated, reflective mode FLC operation.

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

Illustrative embodiments of the invention are described below. In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another.

Moreover, it will be appreciated that such a development effort might be complex and time-consuming, but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

Referring now to Figs. 1A and 1B, prior art transmissive mode FLC or bipolar operation is shown. Light 98 passes through a first polarizer 102 to a $\lambda/2$ FLC or bipolar imager 100, and then to a second polarizer 104, which is 90 degrees rotated from the first polarizer 102. In this description and the drawings, a single cell of the imager is shown, but it is understood that each imager may include a full matrix of individuals cells, each behaving as illustrated. In Fig. 1A, the imager 100 is "on" (rotate) so that the polarization of the light 98 is rotated 90 degrees and the light 98 then passes through the second polarizer 104. The polarization axis (director) of the imager 100 must be 45° with respect to the transmission axis of the polarizer 104. In Fig. 1B, the imager 100 is "off" (non-rotate), so that the polarization of the light 98 is not rotated. The light 98, therefore, does not pass through the second polarizer 104. As noted in the background, when the drive polarity of the imager 100 is inverted for DC balance reasons, the imager 100 changes states from on to off or off to on, so that the DC balance operation causes approximately one-half of the light to be lost for any given cell.

Figs. 2A and 2B illustrate known reflective mode operation of an FLC or bipolar imager. The incoming light 116 impinges on a reflective polarizer 114, such as double brightness enhancement film (DBEF) available from 3M Company. The light 116 is reflected to a $\lambda/4$ FLC or bipolar imager 110. The director of the $\lambda/4$ FLC

110 is oriented 45° with respect to the incoming light 116 polarization. Located behind the imager 110 is a mirror 112 to reflect any light transmitted by the imager 110. After passing through the imager 110 a second time, the reflected light 118 encounters the reflective polarizer 114 a second time. In Fig. 2A, the imager 110 is off, so the light 116 does not have its polarization rotated. The reflected light 118, therefore, also reflects from the reflective polarizer 114. In Fig. 2B, however, the imager 110 is on, and the polarization of the light 116 is rotated by 90 degrees after passing through the λ/4 imager 110 twice. The reflected light 118 then passes through the reflective polarizer 114. Again, DC balancing will result in approximately one-half of the light being lost, as in Figs. 1A and 1B.

Figs. 3A, 3B, 3C and 3D illustrate a known way to solve for the optical efficiency loss problem in transmissive mode FLC operation. A λ/2 FLC compensator 106 is placed in series with the imager 100. In practice, the compensator 106 is a single cell, while the imager 100 may be a plurality of individual cells, as discussed above. The compensator 106 is shown as being after the imager 100 with respect to the incoming light 98, but could also be placed ahead of the imager 100 if desired. In operation, the compensator 106 is switched synchronously with the imager 100 for DC balance purposes. Thus, if the imager 100 is on and the compensator 106 is on, as in Fig. 3A, then when electrical state changes for DC balance purposes, both the imager 100 and the compensator 106 change to off, as shown in Fig. 3D. In both cases, the light 98 is not transmitted. Alternatively, if the imager 100 is off and the compensator 106 is on (Fig. 3B), both are switched to imager 100 on and compensator 106 off (Fig. 3C), with light still passing through the second polarizer 104. Thus,

both DC balance electrical states operate properly, and the system has higher optical efficiency as both DC balance states are utilized. The compensator 106 effectively compensates for the negative polarity state of the imager 100 during DC balance conditions.

The $\lambda/2$ compensator 106 in Figs. 3A-3D could not be used in reflective mode because a double pass through the FLC compensator 106 would provide a full-wave of retardation, thus producing no effect. Figs. 4A, 4B, 4C and 4D, however, illustrate a way to solve for the optical efficiency loss problem in reflective mode FLC operation, in accordance with an embodiment of the invention. In Figs. 4A-4D, a $\lambda/4$ compensator 120 is instead used in series with the imager 110. While the compensator 120 is conceptually a $\lambda/4$ wave plate, a wave plate of any odd multiple of $\lambda/4$, for example, $3\lambda/4$, $5\lambda/4$, etc., may be satisfactory. If an odd multiple greater than $\lambda/4$ is used, the higher necessary drive voltage could be provided by an external transistor or switch, in contrast to the integrated transistors typically used in FLC imagers. Additionally, the compensator 120 is a single cell while the imager 110 may be a plurality of individual cells.

The four states of the reflective mode system are shown in Figs. 4A-4D, with Figs. 4A and 4D being complementary, and Figs. 4B and 4C also being complementary, for DC balance purposes. In Figure 4A, the imager 110 and the compensator 120 are both on (rotate). The incoming light 116 is reflected from the reflective polarizer 114 to the compensator 120, which changes the light to circular polarization. The director of the $\lambda/4$ compensator 120 must be oriented 45° with

respect to the incoming light 116 (linear) polarization in order to achieve circularly polarized light. The light then passes through the imager 110, reflects from the mirror 112, and then travels back through the imager 110. The reflected light 118, which is still circularly polarized, then passes through the compensator 120 where it emerges in the same polarization state as the incoming light 116. Therefore, the light 118 is reflected by the reflective polarizer 114. When the electrical polarity of the imager 110 and the compensator 120 are inverted synchronously for DC balance reasons, operation is as shown in Fig. 4D. Figs. 4B and 4C are similar, except that the light 118 passes through the reflective polarizer 114. The light 118 will pass through the reflective polarizer 114 because only one of the $\lambda/4$ elements (i.e., the compensator 120 in Fig. 4B or the imager 110 in Fig. 4C) is on while the other is off, and the reflective polarizer 114 passes light having the polarization of the reflected light 118 after the compensator 120 in such a circumstance. Thus, the use of the $\lambda/4$ FLC compensator 120 in conjunction with the $\lambda/4$ FLC imager 110 provides high optical efficiency for reflective mode operation.

In Figs. 2A, 2B, 4A, 4B, 4C and 4D, it is to be understood that instead of using the beamsplitting polarizer 114, the light could be projected at the imager 110 and the mirror 112 at an oblique angle, with separate polarizers, as in Figs. 1A and 1B. In that case, either a $\lambda/4$ compensator could be used if both the incoming and reflected light impinged on the $\lambda/4$ compensator, or a $\lambda/2$ compensator could be used if the $\lambda/2$ compensator were placed only in the incoming or the reflected light path.

The particular embodiments disclosed above are illustrative only, as the invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the invention. Accordingly, the protection sought herein is as set forth in the claims below.